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Power distribution algorithm based on game theory in the femtocell system

MU Shi-yao, ZHU Qi (✉)

Jiangsu Key Lab of Wireless Communications, Key Lab on Wideband Wireless Communications and Sensor Network Technology of Ministry of Educations, Nanjing University of Posts and Telecommunications, Nanjing 210003, China

Abstract

This paper studies the power control problem in femtocell system based on Nash non-cooperative game theory. It designs an utility function taking fem stations' transmit power as variable and relates it to the requirements of macro users' and fem users' signal to interference plus noise ratio (SINR). The utility also takes the impact of fem stations' location into account and improves the fairness of non-cooperative game. On this basis, this paper proposes a distributed power control algorithm and proves the existence and uniqueness of Pareto optimal point. The simulation results show that the algorithm improves the convergence speed and system performance through improving users' SINR.

Keywords Nash non-cooperative game, power control, utility function

1 Introduction

Femtocells, are small cellular base stations and being widely used in the family rooms or small commercial organizations [1]. With reasonable distribution of femtocells' transmit power, the interference in the femtocell system which is the biggest problem of its promotion can be properly reduced.

Game theory, as one of the methods to distribute power, is widely used in the cognitive radio. Taking the similarities between cognitive radio and femtocells into account, it can be introduced into femtocell system. Ref. [2] uses Nash equilibrium to allocate power in cognitive system which can be introduced. Ref. [3] uses the Stackelberg mechanisms to allocate power. Refs. [4] and [5] introduce Nash equilibrium into femtocell system, but they just borrow the utility function from the cognitive radio without consideration of the differences between systems of cognitive radio and femtocell. Ref. [6] holds that game theory is a useful mathematical tool to deal with the interactive options and strategies of the users with conflicts of interests.

This paper introduces Nash equilibrium into femtocell system and makes some improvements to the utility function. The penalty factor is introduced to control femtocells' transmit power, making it tend to a stable value with dynamic iterations. It reduces convergence times compared with Ref. [2], while ensuring macro users' service quality and improving fem users' service quality [2].

2 System model

2.1 System interference model

Consider a macro cell with some femtocells and macro users in it. As shown in Fig. 1, assuming there is no interference among macro users and fem users in the same femtocell by reasonable channel allocation. For simplicity, there depicts one macro user, each femtocell only has a user. Signal from macro station to macro user (solid line 1) will be interfered by signal from fem station to macro user (dashed line 2), signal from fem station to fem user (solid line 2) will be interfered by signal from neighbor fem stations and that from macro station to the fem users (dashed line 2).

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Corresponding author: ZHU Qi, E-mail: zhuqi@njupt.edu.cn
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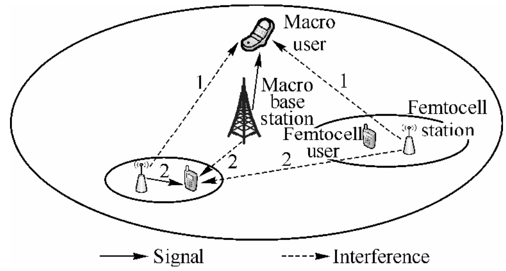

Fig. 1 The interference model of femtocell system

The SINR of fem user i is : $\gamma_i = p_i h_{ii} \Bigg/ \left(\sum_{j=1, j\neq i}^{N} p_j h_{ji} + p_k h_{ki} + \sigma^2 \right)$ $i = 1,2,...,N$ [6], the SINR of macro user k is: $\gamma_k = p_k h_{kk} \Bigg/ \left(\sum_{i=1}^{N} p_i h_{ik} + \sigma^2 \right)$ [6]. Where p_i represents transmit power of fem station i, h_{ii} represents the channel gain between fem station i and its fem user i, p_j represents the transmit power of neighbor fem station j, h_{ji} represents the channel gain from neighbor fem j to fem user i, p_k represents the transmit power of macro base station, h_{ki} represents the channel gain between macro base station k and fem user i, h_{kk} represents the channel gain between macro base station k and macro user k, σ^2 represents noise power. Let γ_i^{target} represents the requirement of fem user i's SINR, then $\gamma_i \geqslant \gamma_i^{\text{target}}$ $\{i = 1,2,...,N\}$ should be guaranteed, N represents the number of femtocells which is also the number of fem users. Let γ_k^{target} represents the requirement of macro user k's SINR, $\gamma_k \geqslant \gamma_k^{\text{target}}$ should be guaranteed.

3 Power control algorithm based on the utility of game theory

3.1 The selection of the utility function

Considering the defects of Ref. [2]'s utility function, this paper proposes a new utility function based on the femtocell system interference model, that is:

$$u_i = \ln(\gamma_i - \gamma_i^{\text{target}}) + \ln(\gamma_k - \gamma_k^{\text{target}}) - w\left(h_{ik} + \sum_{j=1, j\neq i}^{N} h_{ji} \right) p_i \tag{1}$$

where w is the weighting factor to keep the two items' order of magnitude consistent, the first part of utility function is to assure that fem users' SINR meet requirement, the second part is to assure that macro user's SINR meet requirement, the third part is penalty factor which is used to control fem stations' transmit power. Because the transmit power of a fem station will influence neighbor fem users and macro users, penalty factor is related to the channel gain from this fem station to neighbor fem users and the macro user.

3.2 Power iterative algorithm

The problem of fem stations' power control algorithm can be transformed into the problem of Non-cooperative power control game theory: NPGP={$\boldsymbol{I}$,{$\boldsymbol{P}$},{ $u_i(.)$ }}, where, $\boldsymbol{I} = \{1,2,...,N\}$ are the set of ratio fem stations, $u_i(.)$ represents the utility function of fem station i, the strategies chosen by fem stations in one game form transmit power vector $\boldsymbol{P} = (p_1, p_2, ...p_i...p_N)^{\text{T}}$. Femtocells maximize their own utilities at the Pareto optimal point through interactive games. For the i-th femtocell, we have:

$$u_i[p_i^*, \gamma_i(p_i^*, p_{-i})] \geqslant u_i[p_i, \gamma_i(p_i, p_{-i})] \quad \forall p_i, \forall i = 1,2,...,N \tag{2}$$

where p_{-i} represents the transmit power of fem stations except the ith one, p_i^* is the ith's Nash equilibrium power. To obtain the Pareto optimal point, solve the first order partial derivatives of $u_i[p_i, \gamma_i(p_i)]$ about p_i, we can get:

$$\frac{1}{\gamma_i - \gamma_i^{\text{target}}} \frac{h_{ii}}{\sum_{j=1, j\neq i}^{N} p_j h_{ji} + p_k h_{ki} + \sigma^2} - \frac{1}{\gamma_k - \gamma_k^{\text{target}}} \cdot \frac{p_k h_{kk} h_{ik}}{\left(\sum_{i=1}^{N} p_i h_{ik} + \sigma^2 \right)^2} - w\left(h_{ik} + \sum_{j=1, j\neq i}^{N} h_{ji} \right) = 0 \tag{3}$$

Let $I_k(p_{-k}) = \sum_{i=1}^{N} p_i h_{ik} + \sigma^2$, $I_k(p_{-k}) = \sum_{i=1}^{N} p_i h_{ik} + \sigma^2$, then:

$$\frac{1}{\gamma_i - \gamma_i^{\text{target}}} = \left[\frac{1}{\gamma_k - \gamma_k^{\text{target}}} \frac{h_{ik}\gamma_k^2}{p_k h_{kk}} + w\left(h_{ik} + \sum_{j=1, j\neq i}^{N} h_{ji} \right) \right] \frac{I_i(p_{-i})}{h_{ii}} \tag{4}$$

When $\gamma_k - \gamma_k^{\text{target}} \geqslant 0$, $\gamma_i \geqslant \gamma_i^{\text{target}}$, Eq. (4) can be write as:

$$\frac{1}{\gamma_k - \gamma_k^{\text{target}}} \frac{p_k h_{kk} h_{ik}}{I_k^2(p_{-k})} = \frac{1}{\gamma_i - \gamma_i^{\text{target}}} \frac{\gamma_i}{p_i} - k\left(h_{ik} + \sum_{j=1, j\neq i}^{N} h_{ji} \right) \tag{5}$$

In the right side of Eq. (5), γ_i and $\gamma_i - \gamma_i^{\text{target}}$ are in